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NON-PROVISIONAL UTILITY PATENT APPLICATION:

ULTRA-WIDEBAND COMMUNICATION PROTOCOL

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ULTRA-WIDEBAND COMMUNICATION PROTOCOL

This application is a continuation-in-part of co-pending United States non-provisional application Serial No. 10/663,174 filed September 15, 2003, entitled "ULTRA-WIDEBAND COMMUNICATION PROTOCOL."

Field Of The Invention

The present invention relates to the field of wireless communications. More particularly the present invention describes a communication protocol for ultra-wideband communications.

Background Of The Invention

The Information Age is upon us. Access to vast quantities of information through a variety of different communication systems are changing the way people work, entertain themselves, and communicate with each other. Faster, more capable communication technologies are constantly being developed. For the manufacturers and designers of these new technologies, achieving "interoperability" is becoming an increasingly difficult challenge.

Interoperability is the ability for one device to communicate with another device, or to communicate with another network, through which other communication devices may be contacted. However, with the explosion of different communication protocols

(i.e., the rules communications equipment use to transfer data), designing true interoperability is not a trivial pursuit.

For example, most wireless communication devices employ conventional "carrier wave," or radio frequency (RF) technology, while other devices use electro-optical technology. Generally, each one of these communication technologies employ their own communication protocol.

Another type of communication technology is ultra-wideband (UWB). UWB technology is fundamentally different from conventional forms of RF technology. UWB employs a "carrier free" architecture, which does not require the use of high frequency carrier generation hardware; carrier modulation hardware; frequency and phase discrimination hardware or other devices employed in conventional frequency domain communication systems.

Within UWB communications, several different types of networks, each with their own communication protocols are envisioned. For example, there are Local Area Networks (LANs), Personal Area Networks (PANs), Wireless Personal Area Networks (WPANs), sensor networks and others. Each network may have its own communication protocol.

Therefore, there exists a need for a communication protocol for ultra-wideband communication devices, which will allow for compatibility and coexistence between different networks, and different ultra-wideband devices.

Summary Of The Invention

The present invention provides a common communication protocol for ultra-wideband communications. The present invention provides compatibility and interoperability between ultra-wideband communications devices within various types of networks. In one embodiment, combined, or interleaved data frames having both high and low data transfer rate capability are provided. The low data transfer rate may be used for initial discovery of the type of network that is being accessed, and the high data transfer rate may be used to quickly transfer data within networks that have a high data transfer rate capability.

The present invention may be employed in any type of network, be it wireless, wire, or a mix of wire media and wireless components. That is, a network may use both wire media, such as coaxial cable, and wireless devices, such as satellites, cellular antennas or other types of wireless transceivers.

These and other features and advantages of the present invention will be appreciated from review of the following detailed description of the invention, along with the accompanying figures in which like reference numerals refer to like parts throughout.

Brief Description Of The Drawing

FIG. 1 is an illustration of different communication methods;

FIG. 2 is an illustration of two ultra-wideband pulses;

FIG. 3 illustrates embodiments of combination frames, high data rate frames, and low data rate frames, all constructed according to the present invention; and

FIG. 4 illustrates a wireless network of transceivers constructed according to the present invention.

FIG. 5 illustrates a portion of the radio frequency spectrum;

FIG. 6 illustrates two communication devices constructed according to two embodiments of the present invention;

FIG. 7 illustrates a portion of the radio frequency spectrum and a plurality of radio frequency bands located thereon;

FIG. 8 illustrates three different communication methods;

FIG. 9 illustrates a network of communication devices constructed according to one embodiment of the present invention;

FIG. 10 illustrates two different types of communication methods overlaid upon one another; and

FIG. 11 illustrates a portion of a communication frame constructed according to one embodiment of the present invention.

It will be recognized that some or all of the Figures are schematic representations for purposes of illustration and do not necessarily depict the actual relative sizes or locations of the elements shown. The Figures are provided for the purpose of illustrating one or more embodiments of the invention with the explicit understanding that they will not be used to limit the scope or the meaning of the claims.

Detailed Description Of The Invention

In the following paragraphs, the present invention will be described in detail by way of example with reference to the attached drawings. Throughout this description, the preferred embodiment and examples shown should be considered as exemplars, rather than as limitations on the present invention. As used herein, the "present invention" refers to any one of the embodiments of the invention described herein, and any equivalents. Furthermore, reference to various feature(s) of the "present invention" throughout this document does not mean that all claimed embodiments or methods must include the referenced feature(s).

The present invention provides compatibility and interoperability between ultra-wideband communication devices within various types of networks. In one embodiment, the present invention provides compatibility and interoperability between ultra-wideband communication devices that use different physical-layer air interfaces. The “physical layer” is a layer in a communication protocol that comprises the actual media of the communication transmission. However, in a wireless communication environment, the physical layer is the air. Thus, in wireless communications, the physical-layer air interface comprises the processes and/or rules that wireless communication devices employ to communicate with each other. This interface, or protocol may be in the form of computer software, hardware or both software and hardware. “Interface” and “protocol” may be used interchangeably.

Compatibility between similar communication devices becomes important as the devices achieve penetration into the marketplace. For example, a variety of conventional wireless devices use the unlicensed 2.4 GHz frequency for communications. WiFi,

Bluetooth and cordless phones, to name a few. However, because no common communication standard was established, many of these devices cannot communicate with each other, and moreover, many of these devices interfere with each other.

One feature of the present invention is that it enables communication between different types of interfaces employed by different devices.

A preferred embodiment of the present invention provides a protocol designed to facilitate coexistence between multiple devices utilizing different ultra-wideband physical-layer air interfaces.

The Institute of Electrical and Electronics Engineers (IEEE) is currently establishing rules and communication standards for a variety of different networks, and other communication environments that may employ ultra-wideband technology. These different communication standards may result in different rules, or physical-layer air interfaces for each standard. For example, IEEE 802.15.3(a) relates to a standard for ultra-wideband Wireless Personal Area Networks (WPANs). Ultra-wideband may also be employed in IEEE 802.15.4 (a standard for sensors and control devices), 802.11n (a standard for Local Area Networks), ground penetrating radar, through-wall imaging, and other networks and environments. Each one of these devices may employ ultra-wideband communication technology, and each device may also have its own communication standard.

As ultra-wideband technology achieves widespread penetration into the marketplace, compatibility between ultra-wideband enabled devices will become important. One feature of the present invention is that it insures reliable communications between ultra-wideband devices sharing dissimilar physical-layer air interfaces.

Another feature of the present invention is that it may be employed in any type of network, be it wireless, wired, or a mix of wire media and wireless components. That is, a network may use both wire media, such as coaxial cable, and wireless devices, such as satellites, or cellular antennas. As defined herein, a network is a group of points or nodes connected by communication paths. The communication paths may be connected by wires, or they may be wirelessly connected. A network as defined herein can interconnect with other networks and contain subnetworks. A network as defined herein can be characterized in terms of a spatial distance, for example, such as a local area network (LAN), a personal area network (PAN), a metropolitan area network (MAN), a wide area network (WAN), and a wireless personal area network (WPAN), among others. A network as defined herein can also be characterized by the type of data transmission technology in use on it, for example, a TCP/IP network, and a Systems Network Architecture network, among others. A network as defined herein can also be characterized by whether it carries voice, data, or both kinds of signals or data. A network as defined herein can also be characterized by who can use the network, for example, a public switched telephone network (PSTN), other types of public networks, and a private network (such as within a single room or home), among others. A network as defined herein can also be characterized by the usual nature of its connections, for example, a dial-up network, a switched network, a dedicated network, and a nonswitched network, among others. A network as defined herein can also be characterized by the types of physical links that it employs, for example, optical fiber, coaxial cable, a mix of both, unshielded twisted pair, and shielded twisted pair, among others. The present

invention may also be employed in any type of wireless network, such as a wireless PAN, LAN, MAN, WAN or WPAN.

The present invention is directed toward ultra-wideband technology, which in one embodiment is a "carrier free" architecture, which does not require the use of high frequency carrier generation hardware, carrier modulation hardware, stabilizers, frequency and phase discrimination hardware or other devices employed in conventional frequency domain communication systems. Conventional radio frequency technology employs continuous sine waves that are transmitted with data embedded in the modulation of the sine waves' amplitude or frequency. For example, a conventional cellular phone must operate at a particular frequency band of a particular width in the total frequency spectrum. Specifically, in the United States, the Federal Communications Commission has allocated cellular phone communications in the 800 to 900 MHz band. Cellular phone operators use 25 MHz of the allocated band to transmit cellular phone signals, and another 25 MHz of the allocated band to receive cellular phone signals.

Referring to FIG. 1, another example of a conventional radio frequency technology is illustrated. 802.11a, a wireless local area network (LAN) protocol, transmits continuous sinusoidal radio frequency signals at a 5 GHz center frequency, with a radio frequency spread of about 5 MHz.

In contrast, ultra-wideband (UWB) communication technology employs discrete pulses of electromagnetic energy that are emitted at, for example, nanosecond or picosecond intervals (generally tens of picoseconds to a few nanoseconds in duration). For this reason, ultra-wideband is often called "impulse radio." That is, the UWB pulses are transmitted without modulation onto a sine wave carrier frequency, in contrast with

conventional radio frequency technology as described above. A UWB pulse is a single electromagnetic burst of energy. A UWB pulse can be either a single positive burst of electromagnetic energy, or a single negative burst of electromagnetic energy, or a single burst of electromagnetic energy with a predefined phase. Alternate implementations of UWB can be achieved by mixing discrete pulses with a carrier wave that controls a center frequency of a resulting UWB signal. Ultra-wideband generally requires neither an assigned frequency nor a power amplifier.

In contrast to the relatively narrow frequency spread of conventional communication technologies, a UWB pulse may have a 2.0 GHz center frequency, with a frequency spread of approximately 4 GHz, as shown in FIG. 2, which illustrates two typical UWB pulses. FIG. 2 illustrates that the narrower the UWB pulse in time, the broader the spread of its frequency spectrum. This is because bandwidth is inversely proportional to the time duration of the pulse. A 600-picosecond UWB pulse can have about a 1.6 GHz center frequency, with a frequency spread of approximately 1.6 GHz. And a 300-picosecond UWB pulse can have about a 3 GHz center frequency, with a frequency spread of approximately 3.2 GHz. Thus, UWB pulses generally do not operate within a specific frequency, as shown in FIG. 1. And because UWB pulses are spread across an extremely wide frequency range or bandwidth, UWB communication systems allow communications at very high data rates, such as 100 megabits per second or greater. A UWB pulse constructed according to the present invention may have a duration that may range between about 10 picoseconds to about 100 nanoseconds.

Further details of UWB technology are disclosed in United States patent 3,728,632 (in the name of Gerald F. Ross, and titled: Transmission and Reception

System for Generating and Receiving Base-Band Duration Pulse Signals without Distortion for Short Base-Band Pulse Communication System), which is referred to and incorporated herein in its entirety by this reference.

Also, because the UWB pulse is spread across an extremely wide frequency range, the power sampled at a single, or specific frequency is very low. For example, a UWB one-watt pulse of one nano-second duration spreads the one-watt over the entire frequency occupied by the UWB pulse. At any single frequency, such as at the carrier frequency of a CATV provider, the UWB pulse power present is one nano-watt (for a frequency band of 1GHz). This is calculated by dividing the power of the pulse (1 watt) by the frequency band (1 billion Hertz). This is well within the noise floor of any communications system and therefore does not interfere with the demodulation and recovery of the original signals. Generally, the multiplicity of UWB pulses are transmitted at relatively low power (when sampled at a single, or specific frequency), for example, at less than -30 power decibels to -60 power decibels, which minimizes interference with conventional radio frequencies. However, UWB pulses transmitted through most wire media will not interfere with wireless radio frequency transmissions. Therefore, the power (sampled at a single frequency) of UWB pulses transmitted though wire media may range from about +30 dBm to about –140 dBm.

Referring now to FIG. 3, combination, or interleaved frames 10 constructed according to one embodiment of the present invention are illustrated. A "frame" as defined herein may include several different embodiments. Generally, a frame is data that is transmitted between communication points (i.e., mobile or fixed communication devices) as a unit complete with addressing and other protocol information. That is, a

frame is configured by a set of rules and carries data between communication devices. In one embodiment, a frame includes data to be transmitted, error-correcting information for the data, an address, timing or synchronization information, and other features and functions depending on the protocol that the frame was formed under. A frame may include another frame within it, that may be configured, and/or used by a different protocol. A frame may also be configured similar to a Time Division Multiple Access (TDMA) frame.

As shown in FIG. 3, the combination frames 10 include both low data rate (LDR) frames 10(a) and high data rate (HDR) frames 10(b). Each LDR frame 10(a) may be configured to transmit data at a rate that may range between about 1 kilobit per second to about 5 megabits per second. Each HDR frame 10(b) may be configured to transmit data at a rate that may range between about 5 megabits per second to about 1 gigabit per second.

One feature of the present invention is that low data rate ultra-wideband (UWB) devices and high data rate UWB devices may communicate with each other through the use of combination frames 10. For example, one type of UWB device may use a protocol that is only capable of communication at relatively low data rates, while another UWB device may use a protocol that is capable of communication at relatively high data rates.

A UWB communication device employing the combination frames 10 protocol of the present invention would be able to communicate with both low and high data rate UWB devices. For example, a number of different applications of UWB technology have been proposed, with each having its own data rate capability. In a UWB PAN, the data rates may approach 480 Mbps and distances may be limited to 10 meters. In a LAN

application the data rate may be variable dependent on the distance from the network access point. For example, if a UWB communication device is 10-meters from the access point, the data rate may be 500 Mbps. A user farther from the access point may have a 200 Mbps data rate. At a 100-meter distance from the access point the data rate may be only a few megabits per second. Another proposed application for UWB communications technology is a low data rate control and sensor data system. The low data rate application may be good for communicating geographic location information, and other low data rate information. A UWB device employing a communication protocol using combination frames 10 would be able to communicate with any or the above-described UWB networks and devices.

A UWB device constructed according to the present invention may employ both a low and a high data rate transceiver. A UWB device may be a phone, a personal digital assistant, a portable computer, a laptop computer, a desktop computer, a mainframe computer, video monitors, computer monitors, or any other device employing UWB technology.

Low data rate transceivers generally use small amounts of energy, with high data rate transceivers generally using significantly more energy. One advantage of the present invention is that a UWB communication device employing both a low and high data rate transceiver may use the low data rate (LDR) portion for discovery, control, network log on, and protocol negotiation while the high data rate (HDR) portion is powered down, thus conserving power and extending battery life. For example, the LDR transceiver may signal a local UWB device or network, and discover its communication capabilities. The LDR transceiver may then synchronize with the local UWB device/network and provide

the synchronization information to the HDR transceiver, which until now, has been in sleep mode, thereby conserving energy. This type of communication sequence would employ a communication protocol that would use the combination frames 10 discussed herein.

As shown in FIG. 3, the combination, or interleaved sequence in combination frames 10 shows Low Data Rate (LDR) frames 10(a) interleaved with high data rate (HDR) frames 10(b). The frequency of occurrence of LDR frames 10(a) may vary with application and may be additionally dependent on the bandwidth demand of the device with which communication is desired. For example, the number of LDR frames 10(a) may increase when communicating with a low data rate device, and decrease when communicating with a high data rate device.

Both LDR frames 10(a) and HDR frames 10(b) are comprised of groups of symbol slots (not shown). The number of symbol slots in a frame may vary from about 100 to about 100,000. In one embodiment, each symbol slot is comprised of 25 time bins (not shown), with each time bin sized at about 400 picoseconds. Other time bin arrangements, with different time bin sizes, may also be constructed. Within one or more of these time bins, an ultra-wideband (UWB) pulse may be positioned, depending on the data modulation technique that is employed. That is, the position, amplitude, phase or other aspect of the UWB pulse(s) within one, or more of the time bins comprising a symbol slot represents one or more binary digits, or bits, that comprise the data that is being transmitted or received. A group of these symbol slots comprise a LDR frame 10(a) or HDR frame 10(b), thereby enabling the transmission and reception of data.

In one embodiment of the present invention, LDR frames 10(a) and/or HDR frames 10(b) may have a duration that may range between about one (1) microsecond to about one (1) millisecond.

For example, in one embodiment, the LDR frames 10(a) may be arranged as follows: As shown in FIG. 3, the LDR frame comprises many symbol slots (as discussed above) that may be allocated into groups that provide different communication functions. Positioned within each symbol slot are groups of time bins that have one or more UWB pulses located therein. The LDR frame may include an extended preamble and synchronization time 20(a). The preamble and synchronization time 20(a) may be extended to ensure sufficient time for a UWB transceiver to achieve a synchronization lock. The LDR frame may additionally include a control section 20(b) to pass control messages and responses to and from a UWB device. These control messages may include power on, power off, and frame number assignments for communications. Time period 20(c) may be utilized by the transceiver to send geographic location information to a remote UWB device. A contention-based bandwidth request 20(d) may be provided to allow UWB devices to request bandwidth from a network. That is, a number of contention-based methods such as ALOHA, slotted ALOHA, and sensing algorithms with and without collision detection may be used to request time in the network for data transmission. The data payload time period 20(e) of the LDR frame is used to pass low-data-rate data to and from a device/network. Data error detection and correction is provided in time period 20(f). It will be appreciated that the construction of LDR frame may be varied to suit different protocols, and communication needs.

Again referring to FIG. 3, the HDR frame may comprise a smaller preamble and synchronization time period 30(a), a significantly longer data payload time 30(b), and an error detection and correction period 30(c). Additionally, HDR frames may be transmitted at a different power level than LDR frames. The length, or time duration of LDR frames and HDR frames may vary with the environment in which the communication system is installed. In situations where there is more probability of losing synchronization in mid-frame, the length, or time duration of the frames may be reduced.

For example, to increase the quality and reliability of communication, each frame 10(a) or 10(b) may have an amount of "guard time," which comprises time bins that are intentionally left empty. These empty time bins help the UWB device to locate the portion of the frame that contains UWB pulses. Depending on the communication modulation technique employed and/or the communications environment, the amount of guard time may be adjusted to accommodate multipath interference. In one embodiment, the number of LDR frames 10(a) may be significantly lower than HDR frames 10(b) (in a high data rate network), and less guard time may be required in the LDR frames 10(a). It will be appreciated that frames and time bins may have other durations, and that frames may employ different numbers of time bins.

Referring now to FIG. 4, which illustrates one or more network(s) of UWB devices 60(a) – 60(e). A UWB high-low data rate communication device 60 constructed according the present invention contains both a high data rate (HDR) transceiver and an low data rate (LDR) transceiver. All of the devices 60 and 60(a)-(e) include communication antennas 70. The high-low data rate communication device 60 includes

communication protocol computer logic in either a hardware and/or software form that constructs combination frames 10 as discussed above. Thus, the high-low data rate communication device 60 may communicate with device 60(a) that is simply a UWB sensor (or ground penetrating radar, through-wall imager, precision locator, etc.), and can only communicate using low data rates. Or, high-low data rate communication device 60 may communicate with device 60(d), that is a mainframe computer which acts as a master transceiver that manages communications on a high data rate ultra-wideband network.

Thus, one feature of the present invention is that by providing a common signaling protocol that may communicate with all UWB communication devices, a UWB device employing one type of protocol with a low data rate may communicate with a network access point employing a different protocol using a high data rate.

Another feature of the present invention is that in an environment with multiple network access points, the high-low data rate communication device 60 may communicate with all available access points and log onto the most suitable network. For example, a high data rate mobile device whose transmitted signal occupies the entire available bandwidth may communicate when presented with a low data rate network access point.

Or, the high-low data rate communication device 60 may substantially simultaneously contact: a network access point that employs Orthogonal Frequency Division Multiplexing (OFDM); an access point whose high data rate signal occupies the entire available bandwidth; and a low data rate sensor, and the device 60 may contact each one across a low data rate channel using the common signaling protocol of the

present invention. The device 60 and the access points may then do discovery across the low data rate channel. The low data rate access point and the OFDM style high data rate access point may offer connection across only the low data rate channel, to accommodate the low data rate sensor. The high data rate access point may offer either a high or a low data rate channel to the high-low data rate communication device 60. In this example, the high-low data rate communication device 60 may select to log onto the high data rate network.

Another feature of the present invention is that the LDR transceiver may send a power-on or wake-up signal to the HDR transceiver, both located within the high-low data rate communication device 60. In this embodiment, the LDR transceiver may additionally provide a coarse timing reference to the HDR transceiver, thus assisting with time synchronization.

Within a network, an initialization protocol for a fixed access point in the network may involve a listening time period prior to beacon initialization. In one feature of the present invention, if a beacon from a first access point is detected, a second access point may synchronize to the beacon signal emitted by the first access point. It is possible that these access points may be connected by a wire medium, such as fiber-optic cable, coaxial cable, twisted-pair wire, or other wire media. In this type of environment, the synchronization and initialization of an additional access point may be accomplished via the wire medium.

Again referring to FIG. 4, in another embodiment of the present invention, a fixed network access point, or master transceiver, such as 60(d) may periodically transmit a beacon signal at a low data rate. This beacon signal may include the geographic location

of the master transceiver 60(d). A mobile high-low data rate communication device 60 that moves within the coverage area of the master transceiver 60(d) receives the beacon signal with the LDR transceiver and may use the geographic location information to assist in calculating its geographic location. Since the beacon signal may be primarily used for discovery, and logon, the signal modulation technique used for the beacon signal may alternate between techniques used by various transceivers. For example, the beacon signal may alternate between an on-off keying (OOK) signal that occupies a significant portion of the available bandwidth and an OFDM style signal. In this manner a transceiver expecting an OFDM style signal will be able to receive the low data rate frames and complete discovery using those beacon signals, while another type of transceiver may use the OOK beacon signal. Alternatively, a modulation method called binary phase shift keying (BPSK) may be employed by the present invention.

As mentioned above, there are several different types of signal modulation techniques and methods. Ultra-wideband pulse modulation techniques enable a single representative data symbol to represent a plurality of binary digits, or bits. This has the obvious advantage of increasing the data rate in a communications system. A few examples of modulation include: Pulse Width Modulation (PWM); Pulse Amplitude Modulation (PAM); and Pulse Position Modulation (PPM). In PWM, a series of predefined UWB pulse-widths are used to represent different sets of bits. For example, in a system employing 8 different UWB pulse widths, each symbol could represent one of 8 combinations. This symbol would carry 3 bits of information. In PAM, predefined UWB pulse amplitudes are used to represent different sets of bits. A system employing PAM16 would have 16 predefined UWB pulse amplitudes. This system would be able to

carry 4 bits of information per symbol. In a PPM system, predefined positions within an UWB pulse timeslot are used to carry a set of bits. A system employing PPM16 would be capable of carrying 4 bits of information per symbol. All of the above-described signal modulation methods, as well as others (such as ternary modulation, 1-pulse modulation and others) may be employed by the present invention.

Another feature of the present invention is that the LDR frames (shown in FIG. 3) may provide a variety of functionalities, such as remote shut-down or wake-up of a selected UWB device, and wireless update of firmware of the selected UWB device. Updating the firmware of the UWB device allows for the device to avoid early obsolescence in a rapidly changing technology environment.

Referring now to FIGS. 5-11, additional embodiments and features of the present invention are illustrated. FIG. 5 illustrates a portion of the radio frequency spectrum, showing the frequency band of 3.1 GHz to 10.6 GHz, where ultra-wideband communication is allowed, and 2.4 GHz to 2.4835 GHz where 802.11, its derivatives such as Bluetooth and others, and other devices are permitted to operate.

One feature of the present invention, as embodied in the ultra-wideband (UWB) high-low data rate device 60, or any one of the UWB devices 60 a-e, shown in FIG. 4, is that communication using low data rate (LDR) frames 10(a) may be at one radio frequency, and communication using high data rate (HDR) frames 10(b) may be at another radio frequency. That is, information transmitted using LDR frames 10(a) may be transmitted at a different radio frequency than information transmitted using HDR frames 10(b).

For example, referring to FIG. 5, which illustrates a lower frequency band 40 and a higher frequency band 42. In this illustration, the lower frequency band 40 comprises the unlicensed radio frequencies that extend from 2.4 GHz to 2.4835 GHz, and the higher frequency band 42 comprises 3.1 GHz to 10.6 GHz, which allows ultra-wideband communications. In this embodiment, LDR frames 10(a) may be transmitted as a Bluetooth-like signal. Alternatively, LDR frames 10(a) may be transmitted using a conventional carrier wave transmitted at other radio frequencies that are not shown in FIG. 5. Or, LDR frames 10(a) may be transmitted using ultra-wideband pulses that only use a portion of the 3.1 GHz to 10.6 GHz frequency band. HDR frames 10(b) may be transmitted using ultra-wideband pulses that use a different portion of the 3.1 GHz to 10.6 GHz frequency band. It will be appreciated that the exact radio frequencies employed by the LDR frames 10(a) and the HDR frames 10(b) may be other than those illustrated.

One feature of this embodiment is that the HDR transceiver in UWB high-low data rate device 60 does not have to cease transmission to allow the LDR frames 10(a) to be transmitted by the LDR transceiver. Since there is frequency separation between the LDR frames 10(a) and the HDR frames 10(b), the two signals, or pulse groups will not interfere with each other. Another feature of this embodiment is that by transmitting the LDR frames 10(a) on a conventional carrier wave, the carrier may be used to assist any of the UWB devices 60a-e in synchronization by providing a continuous signal for the UWB devices 60a-e to determine their timing reference.

Referring now to FIG. 6, alternative embodiment communication devices 44 and 50 are illustrated. Multi-data rate device 44 comprises an antenna 70, low data rate

(LDR) transceiver 48 and a high data rate (HDR) transmitter 46. The multi-data rate device 44 also includes a variety of other components (not shown) such as controller(s), digital signal processor(s), waveform generator(s), static and dynamic memory, data storage device(s), amplifier(s), filter(s), interface(s), modulator(s), demodulator(s), other necessary components, or their equivalents. The controller may include error control, and data compression functions. The multi-data rate device 44 may employ hard-wired circuitry used in place of, or in combination with, software instructions. Thus, embodiments of the multi-data rate device 44 are not limited to any specific combination of hardware or software. The multi-data rate device with band pass filters 50 may be constructed similar to the multi-data rate device 44, with the addition of band pass filters (BPF) 52. The BPFs 52 may be used to crop, or otherwise alter the pulses, or signals emitted by the multi-data rate device with band pass filters 50.

One feature of both the multi-data rate device 44 and the multi-data rate device with band pass filters 50 is that they only contain an HDR transmitter 46, not a HDR transceiver, or a HDR receiver. That is, both communication devices 44 and 50 are structured to transmit data at both high and low data rates, but only receive data at low data rates. In one communication method of the present invention, the low data rate (LDR) transceiver 48 negotiates login, data transfer protocol(s), and other functions with a network or other device. For example, a camcorder, digital camera, audio recorder, or other device may only need an asymmetrical data transfer capability. Once the LDR transceiver 48 has accessed a network or device, such as a computer or stereo system, the HDR transmitter 46 is activated, and downloads, or transmits data stored in the communication devices 44 and 50. Because the camcorder, or other device may only

send large amounts of data in one direction, having a bi-directional high data rate capability may be unnecessary. In this communication method, all communication from the network, or other device, back to the communication devices 44 and 50 are conducted by LDR transceiver 48. One feature of this embodiment is that the data transfer rate from the communication devices 44 and 50 to a network, or other device may be increased, but power usage is minimized because only the LDR transceiver 48 is used during initial communication. In addition, by eliminating a HDR receiver, manufacturing and subsequent resale costs are reduced.

As discussed above in connection with FIG. 6, in one method of the present invention, the LDR transceiver 48 initiates all communication. The information included in this low data rate transmission may include network log-on and authentication information, geographic location information, software and firmware revision number, timing of low data rate transmission information, and other information. For example, low data rate transmission information may additionally include a description of the high data rate capability of the communication devices 44 and 50. Other information contained within the low data rate transmission may include a request for a high data rate transmission time period. Within this request the communication devices 44 and 50 may send their requested data rate, type of data to be transmitted, quality of service (QOS) requirements, and size of data to be sent. In a contention based communication protocol environment, such as ALOHA or slotted ALOHA, access to the network, or to other devices, may be requested by transmitting the communication devices 44 and 50 unique Medium Access Control (MAC) address.

Prior to any communication, the communication devices 44, 50, 60 and 60a-e may perform a "clear channel assessment." This aspect of the invention is discussed above as a "listening time period." This clear channel assessment (CCA), or listening time period, comprises listening to the radio frequency band for a period of time prior to transmission in the same band, or adjacent bands. The CCA may further comprise mapping or otherwise analyzing any signals present in the frequency band(s) of interest.

By mapping, or otherwise analyzing any signals present in frequency band(s) of interest, the communication devices 44, 50, 60 and 60a-e may determine if transmission may cause interference with other signals. Alternatively, the communication devices 44, 50, 60 and 60a-e may transmit signals or pulses that have been created or shaped to avoid frequencies where signals are present.

In another embodiment of the present invention, data transmitted at low data rates versus high data rates may be transmitted on signals, or pulses, that have different properties. For example, the low and high data rate data may be transmitted with different pulse shapes. In one embodiment the pulse shapes are selected to be mutually orthogonal to each other. In this embodiment pulse shape $P_1(t)$ and $P_2(t)$ are selected to meet the orthogonality condition where the cross-correlation of the two pulse shapes is equal to zero, as shown in the following equation:

$$\int P_1(t)P_2(t)dt = 0$$

Orthogonality, as described above, reduces the potential interference between pulses and makes it easier for a receiver to discriminate between the two pulses.

In another embodiment the low data rate information may be encoded using differential phase shift keying (DPSK). In ultra-wideband DPSK, two pulses are

substantially identical to each other except for their polarity. Information is encoded onto the pulses by assigning a data bit to the transition (i.e., polarity change) from a previous pulse to the current pulse. For example, when a data bit to be sent is a one (1), the current pulse has the same polarity as the previous pulse. When the data bit is a zero (0), the current pulse has the opposite polarity.

One advantage of DPSK over other phase modulation schemes is that a receiver may be less complex. One type of correlating receiver used to detect BPSK signals may use a local template signal that is generated and multiplied by an incoming pulse. The resultant product is then integrated to determine the correlation of the incoming pulse with the template signal. If the incoming pulse is of the same phase as the template, the integral will be positive. If the incoming pulse is of opposite phase, the integrand will be negative. However, this type of correlating receiver may suffer from increased error in an environment where the incoming pulse is difficult to match with a locally generated template signal. Reduced signal-to-noise (SNR) ratios due to increased noise environments may cause the received pulse to be difficult to match with the template signal.

But, in an ultra-wideband DPSK receiver, the current pulse is correlated, with a multiplier followed by integration, with the proceeding pulse. Since the two pulse shapes are identical except for polarity, there are two possibilities. The current pulse is either of the same polarity as the proceeding pulse, wherein the integral output is positive, or the current pulse is of opposite polarity as the proceeding pulse, and the integral output will be negative. Given a first reference pulse of a known data value, the rest of the data stream may be decoded. One advantage of an ultra-wideband DPSK receiver is that both

the current and proceeding pulses are subject to the same noise environment and the receiver will have a similar SNR when receiving both pulses. Additionally, an ultra-wideband DPSK receiver may have reduced cost and complexity because there is no need to generate a local template signal.

Another feature of the present invention is that a pseudo-random timing sequence may be employed to transmit LDR frames 10(a) and HDR frames 10(b). This may avoid the generation of spectral lines. That is, if LDR frames 10(a) and HDR frames 10(b) are interleaved at a fixed rate, or period, the difference in communication parameters between frame types, such as power and type of modulation, may cause a significant clustering of energy at specific radio frequencies. These energy clusters, or "spectral lines" may occur at a frequency equal to the inverse of the time between transmission of LDR frames 10(a). Additionally, a spectral line may occur at every integer harmonic of that frequency. For example, if the LDR frames 10(a) are transmitted at a rate of one every microsecond, there may be a spectral line created at 1 megahertz (MHz). Additional lines may be formed at 2 MHz, 3 MHz, 4 MHz, and so on. The creation of spectral lines may cause interference with other signals. To avoid the generation of spectral lines, the communication devices 44, 50, 60 and 60a-e may transmit at a lower power level, which then limits the distance at which they can effectively communicate.

To avoid generating spectral lines, a pseudo-random timing sequence may be employed to transmit LDR frames 10(a) and HDR frames 10(b). By interleaving the LDR frames 10(a) and HDR frames 10(b) in a pseudo-random manner, spectral line formation may be mitigated or reduced. A pseudo-random hopping sequence may be used to determine the location in time of LDR frames 10(a) relative to HRD frames

10(b). In this embodiment, the transmitter and receiver should have prior knowledge of the hopping sequence. This is because even though each communicating device knows the sequence, it appears to be a random sequence to receivers without the hopping sequence. The use of a pseudo-random interleaving sequence generally prevents or dramatically reduces the formation of spectral lines, thereby allowing signals, or pulses to be transmitted at a higher power, enabling longer communication distances.

Yet another feature of the present invention provides a method for load, or bandwidth, balancing between communication devices 44, 50, 60 and 60a-e wishing to transmit data to each other, or to a network access point. As described above, an LDR frame 10(a) may include a contention based time portion, such as ALOHA, slotted ALOHA, or another method, that enables communication devices 44, 50, 60 and 60a-e to request access to a network. As discussed above, the LDR frame 10(a) may include information relating to the type of data to be transmitted. The network access point may then assign a number of HDR frames 10(b) to contending communication devices 44, 50, 60 and 60a-e in an uneven manner, in light of the type, or amount of data to be transmitted. By assigning HRD frames 10(b) in this manner, the network may ensure that users with data requiring reduced latencies (i.e., immediate transmission) may be given time preference over users whose data is less time sensitive.

In this communication method, each device U_i (such as communication devices 44, 50, 60 and 60a-e) requesting access may transmit its requested data rate R_i and the size of the file S_i to be sent. The time T_i for this file transfer may then be calculated as: $T_i = \frac{S_i}{R_i}$. The entire time necessary for N_u devices to transfer their data is then the sum of all times for each device. If "M" HDR frames 10(b) are required for all devices to

complete transmission then: $\sum_{i=1}^{N_u} T_i = MT_f$, where T_f is the time duration of the payload section of a HDR frame 10(b). Assuming that each HRD payload is divided into time slots of T_c duration then the total time to transfer the data may also be expressed as $T_i = MN_iT_c$ if N_i slots of T_c duration are allocated to device U_i within all M frames. It then follows that N_i may be calculated as follows:

$$N_i = \frac{T_i}{MT_c}$$

$$N_i = \frac{\frac{S_i}{R_i}}{\frac{T_c}{T_f}\sum_{i=1}^{N_u} T_i}$$

$$N_i = \frac{N_c S_i}{R_i \sum_{j=1}^{N_u} \frac{S_j}{R_j}}$$

The number of time slots within each HDR frame 10(b) for each device may then be dynamically calculated based on the requirements of all requesting communication devices 44, 50, 60 and 60a-e. The above function may require truncation to the next lower integer for each device which may result in a number of extra time slots that may then be allocated. One feature of this method is that all devices requesting access will be allocated an amount of time relative to the task they wish to accomplish. That is, devices with larger amounts of data to send are allocated more time than devices with smaller data transfer requests.

One feature of the present invention is that dissimilar ultra-wideband (UWB) communication devices that use different UWB architectures, protocols, or interfaces

may coexist in the same environment if the UWB devices are using a common signaling protocol (CSP), as described herein. For example, a UWB device, such as any one of communication devices 44, 50, 60 and 60a-e, may employ a physical layer (PHY) that communicates over multiple sub-bands of the radio frequency spectrum. Another UWB device, that employs a PHY designed to communicate in a single radio frequency band, may communicate with the multiple sub-band UWB device buy using the CSP of the present invention. On feature of the CSP is that it may first attempt to communicate at the lowest available data rate between the devices. In communicating at the lowest data rate, the CSP may employ one, or a set of protocols, that can negotiate time and radio frequency allocation to ensure some level of interoperability between dissimilar devices.

A number of different ultra-wideband PHY's or physical layers are currently under development. In one PHY, the radio frequency band of operation is divided into multiple sub-bands, shown in FIG. 7. Within each sub-band, Orthogonal Frequency Division (OFDM) may be employed. This approach usually requires transmission of data using a number of different frequency bands (such as Bands 1-3) in a time-hopped manner. Currently, the FCC mandates that these frequency bands are at least 500 MHz wide, as shown in FIG. 7. This approach is commonly referred to as Multi-Band OFDM UWB (MBOFDM-UWB).

Another PHY design utilizes significantly larger contiguous portions of the radio frequency spectrum. This system, illustrated in FIG. 8, has a number of different communication modes. In a first mode ("Low Band") the PHY transmits in a single frequency band that is in the lower portion of the available spectrum (around 3 – 5 GHz). An additional mode ("High Band") may use a higher frequency range that extents from

about 6 to about 10 GHz. In a third mode ("Multi-Band"), the PHY may transmit in both the lower and the higher radio frequency bands. This PHY is commonly referred to as Direct Sequence ultra-wideband (DS-UWB), since the data to be transmitted is first spread using direct sequence spreading techniques.

A number of other applications have been proposed for ultra-wideband communication technology. One such application is low data rate sensor networks. In this application the data rates may be substantially lower than what is required for some of the foreseeable uses of either MBOFDM-UWB or DS-UWB.

Because the above PHYs occupy substantially the same radio frequency bands, there is a real potential for inference. The common signaling protocol (CSP) as herein disclosed may negotiate coexistence between dissimilar PHYs. One feature of the CSP of the present invention is that it will negotiate access to frequency bands of interest among dissimilar devices. That is, if any of communication devices 44, 50, 60 and 60a-e employ different PHYs, the CSP of the present invention will enable communication between them.

For example, referring to FIG. 9, which illustrates a Piconet Controller (PNC) 80 communicating with UWB devices 90(a) through 90(c). The PNC 80 may be a fixed network access point, or master transceiver, such as 60(d), discussed above in connection with FIG. 4. Alternatively, the PNC 80 may be a mobile, or fixed device that acts as a controller for a piconet. For example, a PNC 80 may be a MBOFDM-UWB access point. A mobile DS-UWB or low data rate UWB device utilizing the CSP would be able to communicate among all types of communication devices that access the PNC 80.

As shown in FIG. 9, in this exemplary network, devices 90(a) through 90(c) may employ different PHYs. Additionally, PNC 80 may have a PHY that is similar to one of the devices 90(a) through 90(c) but dissimilar to other devices that have access to the PNC 80. In one embodiment of the present invention, the CSP may require the dissimilar devices, such as any one of 90a-c to match the chipping rate of the PNC 80. In this embodiment, the chipping rate may be matched by a rate controller or by interpolation to the other chipping rate. In another embodiment, may of devices 90a-c may implement a chip rate that is an integer multiple of the lowest common divisor between their rates. For example, a MBOFDM-UWB device is known that utilizes radio frequency bands of 528 MHz. In this device, a series of three transmissions are sent in each of three consecutive bands. This aggregates to an effective chipping rate of 1.584 Giga-chips per second (Gcps). A DS-UWB device is known that operates at 1.368 Gcps (Low Band) and at 2.736 Gcps (High Band). In one embodiment of the CSP of the present invention, one of the devices would need to include a rate controller to convert to the other chip rate. Alternatively, one device may interpolate the received signal from its chipping rate to the other chipping rate. Interpolation is well known to one skilled in the art.

Referring now to FIG. 10, which illustrates different radio frequency band width pulses, or signals. A multiple sub-band system such as a MBOFDM-UWB may have a signal that occupies frequency bands 100. A DS-UWB signal may occupy frequency band 110. When a MBOFDM-UWB receiver attempts to receive a signal from a DS-UWB device it will be able to process portions of the bandwidth that are overlapping, as shown in FIG. 10.

Another embodiment CSP of the present invention requires that all UWB devices, such as 80, 90a-c, 44, 50, 60 and 60a-e, add additional low cost hardware that enables communication at the same chipping rate. In one embodiment, the CSP may transmit hierarchical codes such as Golay codes, during a portion of communication between devices. Golay codes are known to have exceptional autocorrelation properties and orthogonal Golay codes may be used to differentiate between different piconets 80.

Referring now to FIG. 11, a preamble format that is included within LDR frame 10(a) and/or HDR frame 10(b) is illustrated. Time period T1 may be provided for the receiver to adjust its automatic gain control (AGC). Time period T2 may be provided for the receiver to measure the power level of distinct receiver chains, or alternatively decide between multiple antennas if the device, such as communication devices 80, 90a-c, 44, 50, 60 and 60a-e, are so equipped. Time period T3 may be provided for the receiver to fine-tune its AGC based on the selections made during time period T2. Time period T4 may be broken into a number of discrete synchronization sequences (S0-S19). It will be appreciated that there may be more or less than the 20 synchronization sequences illustrated. In one embodiment, one or more of the synchronization sequences may be of reverse polarity. Reversing the polarity of one or more synchronization sequences generally improves the probability of correct detection at the end of the synchronization period.

Thus, it is seen a communication protocol for ultra-wideband communication is provided. One skilled in the art will appreciate that the present invention can be practiced by other than the above-described embodiments, which are presented in this description for purposes of illustration and not of limitation. The description and examples set forth

in this specification and associated drawings only set forth preferred embodiment(s) of the present invention. The specification and drawings are not intended to limit the exclusionary scope of this patent document. Many designs other than the above-described embodiments will fall within the literal and/or legal scope of the instant disclosure, and the present invention is limited only by the instant disclosure. It is noted that various equivalents for the particular embodiments discussed in this description may practice the invention as well.